



Memorandum

To: Steven Pudney, C. Eng., MICE, Section Chief – Engineering, Bureau of Water System Engineering

From: Sandra Kutzing, Carol Rego (CDM Smith), Kareem Adeem, Tiffany Stewart and Jerry Notte (City of Newark)

Date: October 15, 2021

Subject: Final CCT Effectiveness – Supplemental Informational on Galvanic Corrosion

This memorandum is in response to the Bureau of Water System Engineering's (Bureau's) letter dated August 23, 2021 requesting supplemental information providing evidence that the corrosion control treatment (CCT), before and after removal of sodium silicate, is effective for controlling lead release from copper pipe with lead solder and associated domestic plumbing in Newark's Pequannock Distribution System. The original report, "Pequannock Gradient Corrosion Control Treatment Effectiveness Evaluation and Pipe Loop Study Results," (CCT Effectiveness Report) dated May 17, 2021 prepared by CDM Smith demonstrated CCT effectiveness in preventing release of lead from lead pipes in both the pipe loop study and in the distribution system. The report also demonstrated CCT effectiveness with galvanic corrosion (i.e. copper with lead solder) in the distribution system compliance sampling, however, the copper with lead solder pipe loops resulted in data inconsistent with the distribution system. This memorandum provides additional data from the pipe loop study through August 2021 and additional information on galvanic corrosion.

Pipe Loop Lead Levels – Copper with Lead Solder Loops

As discussed in the CCT Effectiveness Report, the lead pipes in Racks 2 and 3 showed significant and consistent decreases in lead concentrations compared to the control rack, Rack 1, after zinc orthophosphate was added. The pipe scale analysis will confirm the assumption of a phosphate-based scale forming on the lead pipes in Racks 2 and 3, similar to what is expected to be found in Newark's distribution system.

At the time of the CCT Effectiveness Report submission, the lead levels in the two copper pipes with lead solder and brass fittings treated with zinc orthophosphate (Loop 8 and Loop 12) showed an increase in lead levels starting in November 2020 continuing through March 2021 while the copper pipe with lead solder and brass fittings not treated with zinc orthophosphate (Loop 4) did not see a corresponding increase in lead levels. Figure 1 provides an updated graph with lead levels in the copper pipes with lead solder (Loops 4, 8 and 12) through August 31, 2021.

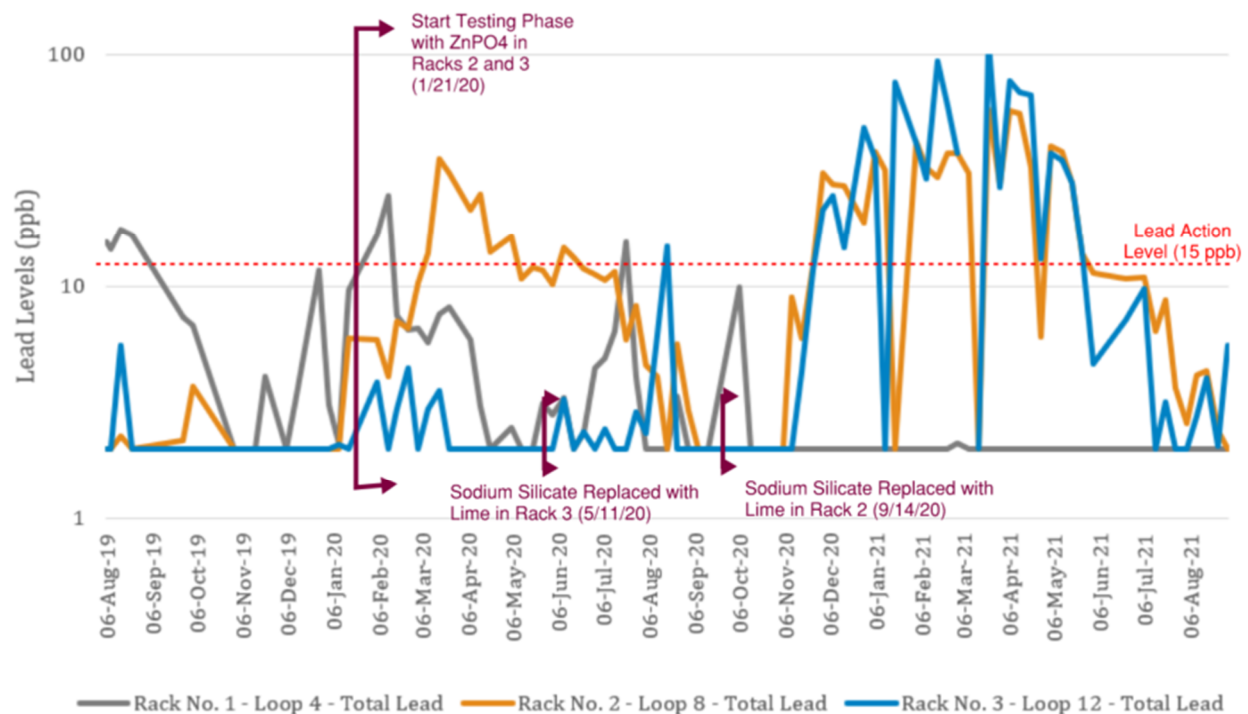


Figure 1 – Total Lead - Conditioning and Testing Phases for the Copper Pipes – Loops 4, 8 and 12

As shown in Figure 1, the lead levels steadily decreased after the CCT Effectiveness Report was provided with data analyzed through March 2021 and after Newark's staff made an effort to maintain a more consistent orthophosphate residual to better reflect the conditions of the distribution system. As shown, lead levels fell below the Lead Action Level of 15 ppb on May 25, 2021 and remained below since that time, falling well below 10 ppb.

Galvanic Corrosion Background

Galvanic corrosion is an electrochemical process where electrons transfer from one metal to another metal in the presence of a conductive solution such as water. In the case of copper with lead solder, the lead solder is corroded and leaches into the drinking water in the absence of a protective scale.

It is well covered in literature and the EPA Optimal Corrosion Control Treatment (OCCT) 2016 Manual that orthophosphate is an effective mechanism for reducing galvanic corrosion. According to the AWWARF Internal Corrosion of Water Distribution Systems, 2nd edition, dated 1996, the corrosion rate for galvanically coupled lead solder is greater than it is for a lead pipe. This means that the protective barrier, such as an orthophosphate scale, would have to be thicker for the lead solder in order to reduce the corrosion rate to the dissolution rate. In addition, the corrosion deposits for lead solder forming the protective layer have a lower mechanical strength.

Based on this, as expected, the presumed lead-phosphate scales on the lead pipes for Racks 2 and 3, appear to be more robust against some inconsistent water quality than the copper pipes. This memorandum reviews several potential causes for an increase in galvanic corrosion without a corresponding increase in corrosion of the lead pipe scales on the same racks or in the copper with lead solder pipe on Rack 1, the control rack. The following are potential factors that could impact galvanic corrosion:

1. Chloride to sulfate mass ratio (CSMR)
2. Orthophosphate residual
3. Silica concentration

pH variability would also have an impact on galvanic corrosion, however, this was evaluated in the CCT Effectiveness Report and no correlation between the pH and the increase in lead levels was found. pH was maintained generally between 7.2 and 7.6 for the majority of the loop study and even when outside of this range, the pH was found to be consistent across the three (3) racks. The cause of the temporary increase in lead levels in Loops 8 and 12 would need to be unique to Racks 2 and 3 since the same increase was not seen in Loop 4. This also eliminates other water quality parameters, such as iron, manganese, chlorine residual and ORP, as the possible cause of the increase in lead levels in Loops 8 and 12 since these parameters were consistent across all three (3) racks for the duration of the pilot.

Chloride to Sulfate Mass Ratio (CSMR)

Recent events in Flint, Michigan and elsewhere have drawn attention to the significance of chloride and sulfate levels in water supplies on lead corrosion. Specifically, the concern is with a change in the proportion of chloride to sulfate, also known as the Chloride to Sulfate Mass Ratio (CSMR). A “high” CSMR can be cause of concern mainly because the high concentration of chloride, as chloride complexes lead ($\text{Pb}^{+2} + \text{Cl}^- \rightarrow \text{PbCl}^-$), with the resulting complex being relatively soluble and not conducive to forming a precipitate (i.e., lead stays in solution).

The literature reports a “threshold” CSMR value of 0.5, above which galvanic corrosion of lead solder on copper piping can increase. However, in CDM Smith’s experience, it is a sudden change or shift in CSMR that leads to concerns. Increases in the CSMR have been associated with galvanic corrosion of lead solder connected to copper pipe in building’s plumbing.

The CSMR of Newark’s Pequannock Gradient was found to be an average of 2.9 in the “Pequannock WTP Corrosion Control Review and Recommendations – Final Report” dated March 15, 2019 (Pequannock OCCT Report). Although this is above the 0.5 threshold, there are many systems that operate with similar or higher CSMRs that do not have high lead levels or Action Level exceedances. The likely reason for this is that much of the solder exposed to the water may have been released at extremely low rates over decades. The research that established the 0.5 threshold value focused on simulating release of lead from solder in water that was abruptly subjected to high CSMR water.

This is corroborated by full-scale experience where the CSMR changed abruptly and significantly in magnitude due to a process or water quality change. In these cases, the “baseline” condition was a relatively low CSMR (oftentimes still greater than 0.5), and the operational change caused a sudden and very large increase in CSMR, which contributed to lead release and spikes in tap water sampling results (Nguyen, C.K. et al., Water Research Foundation, 2010). Newark has not had a drastic change in the CSMR in its Pequannock Gradient for at least 26 years.

The chloride and sulfate levels over the course of the pipe loop study were reviewed and CSMR calculated. Sulfate typically ranges between 9.5 and 10.6 mg/L (approximately 10% seasonal variations). Chloride typically ranges between 32.9 and 41.1 mg/L (approximately 25% seasonal variations) with peaks typically in the winter months likely due to runoff with road salt. As shown in Figure 2, CSMR has been fairly consistent ranging typically between 3 and 4 with only four (4) brief periods with a CSMR above 4.0, in the winter months except for one August measurement when the sulfate concentration dipped slightly. The lead results for Pipe Loop 8 (copper with lead solder loop on Rack 2) are also provided on the graph. As shown there does not appear to be a correlation between the CSMR and the increase in lead concentrations in the copper with lead solder loop. Although only Pipe Loop 8 is shown, Pipe Loop 12 (copper with lead solder loop on Rack 3) followed a similar trend in lead results.

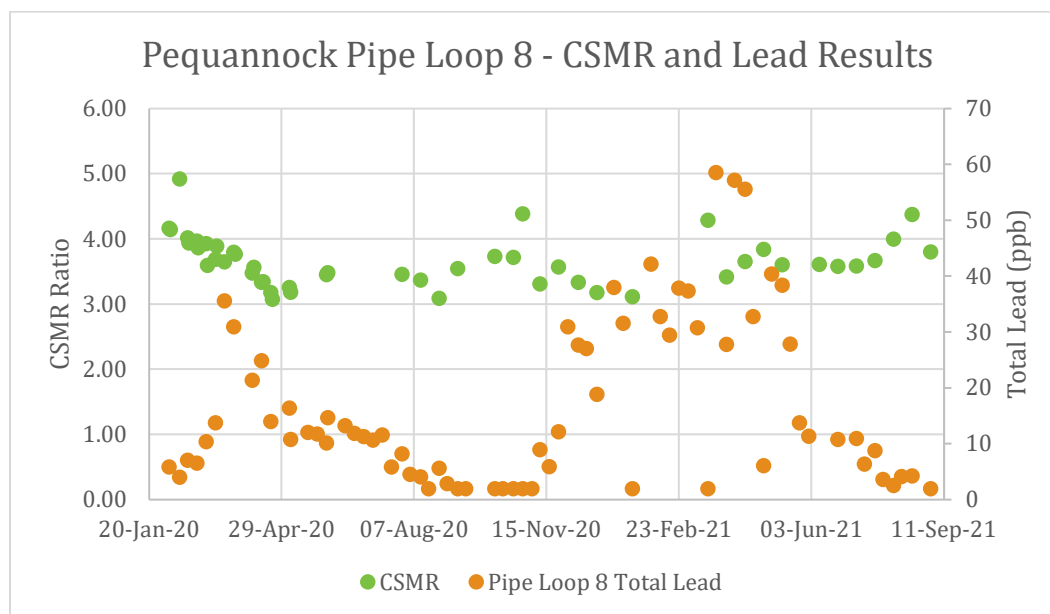


Figure 2 – CSMR and Pipe Loop 8 Lead Results (January 2020-September 2021)

The CSMR results presented in Figure 2 are similar to what is seen in the distribution system as presented in the Pequannock OCCT Report. As the CSMR has been consistent throughout the pipe loop operation and the distribution system has a similar CSMR ratio without an increase in lead at

the tap, it is concluded that the CSMR ratio is not the cause of the increase in lead in the copper with lead solder loops in the on-going loop study.

Orthophosphate Residual

The CCT Effectiveness Report provided in May 2021 suspected that an inconsistent orthophosphate residual was the cause of the lead increase in the galvanic corrosion loops in Racks 2 and 3. At that time, the pipe loop operators were asked to closely monitor the orthophosphate residual and target a consistent dose, even if it is slightly above the target dose of 2.75 mg/L as PO₄. Figure 3 shows orthophosphate residual (yellow shaded area) through the end of August 2021 and corresponding lead concentrations in Loop 8 and Loop 12.

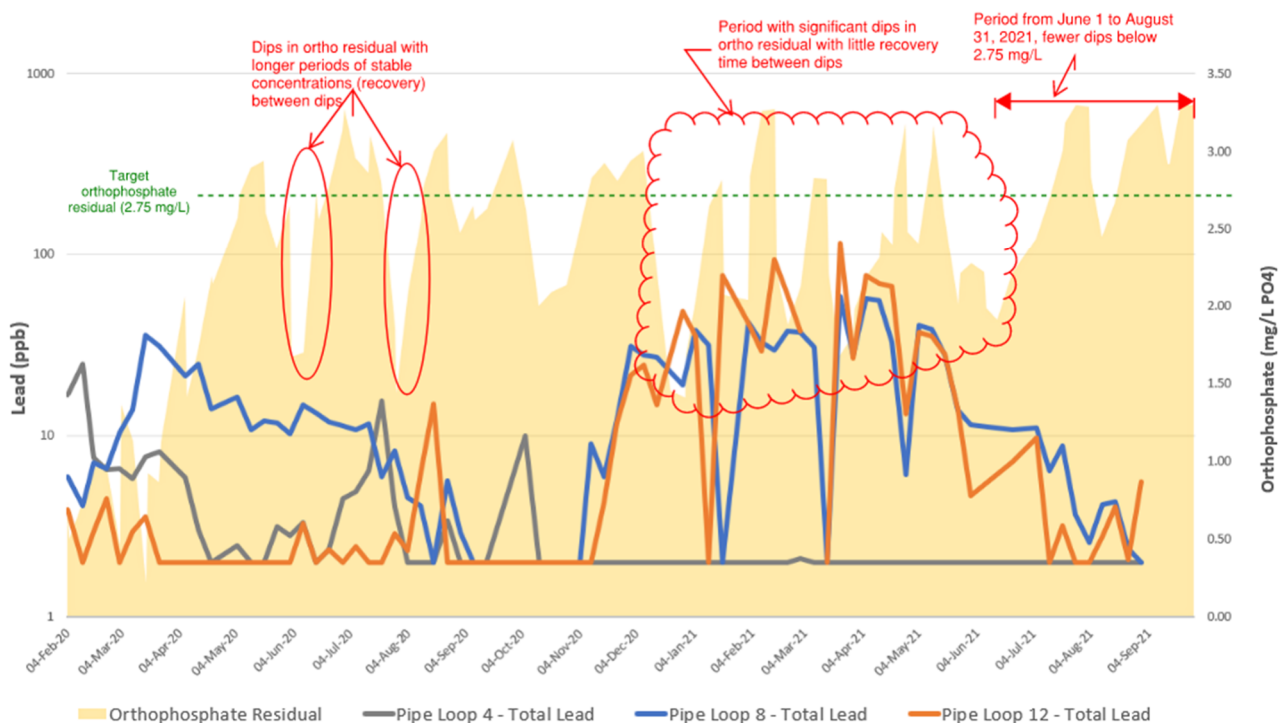


Figure 3 – CSMR and Pipe Loop 8 Lead Results (January 2020-September 2021)

Figure 3 demonstrates that, as the orthophosphate residual became more consistent with fewer depressions below the target dose of 2.75 mg/L as PO₄, the lead levels in Loops 8 and 12 reduced to below 10 ppb. This stresses the importance of a consistent orthophosphate dose in the distribution system for maintaining and further improving the current low levels of lead in the distribution system.

Silica Concentration

The final parameter evaluated to determine if it had an impact on the temporary increase in lead levels in Loops 8 and 12 was silica residual. Newark's source water is naturally high in silica with an average of approximately 4,000 to 5,000 µg/L as SiO₂. Newark currently doses sodium silicate in the Pequannock WTP, raising the silica concentration in the distribution system to approximately 8,000 µg/L as SiO₂.

For the pipe loop study, all loops were initially dosed with sodium silicate with a target dose above what is currently used in the distribution system in order to amplify any potential water quality issues when removing the sodium silicate. Table 1 provides a summary of the sodium silicate dosing for the pilot study.

Table 1 – Summary of Silica Concentrations During Pilot Study

Rack/Loop	Sodium Silicate Use	Testing Phase Silica Residual
Rack 1 / Loop 4	Conditioning phase and testing phase	Average 10,700 µg/L
Rack 2 / Loop 8	Conditioning phase and testing phase until September 14, 2020	9,200 µg/L (Feb – May 2020) 25,000 µg/L (May – Sept 2020) 5,300 µg/L (after stopping sodium silicate feed in Sept 2020)
Rack 3 / Loop 12	Conditioning phase and testing phase until May 11, 2020	8,900 µg/L (Feb – May 2020) 5,000 µg/L (after stopping sodium silicate feed in May 2020)

Figures 4 through 6 show the silica residual concentrations and corresponding stagnated lead concentrations for Loops 4, 8 and 12 during the testing phase of the pilot, respectively.

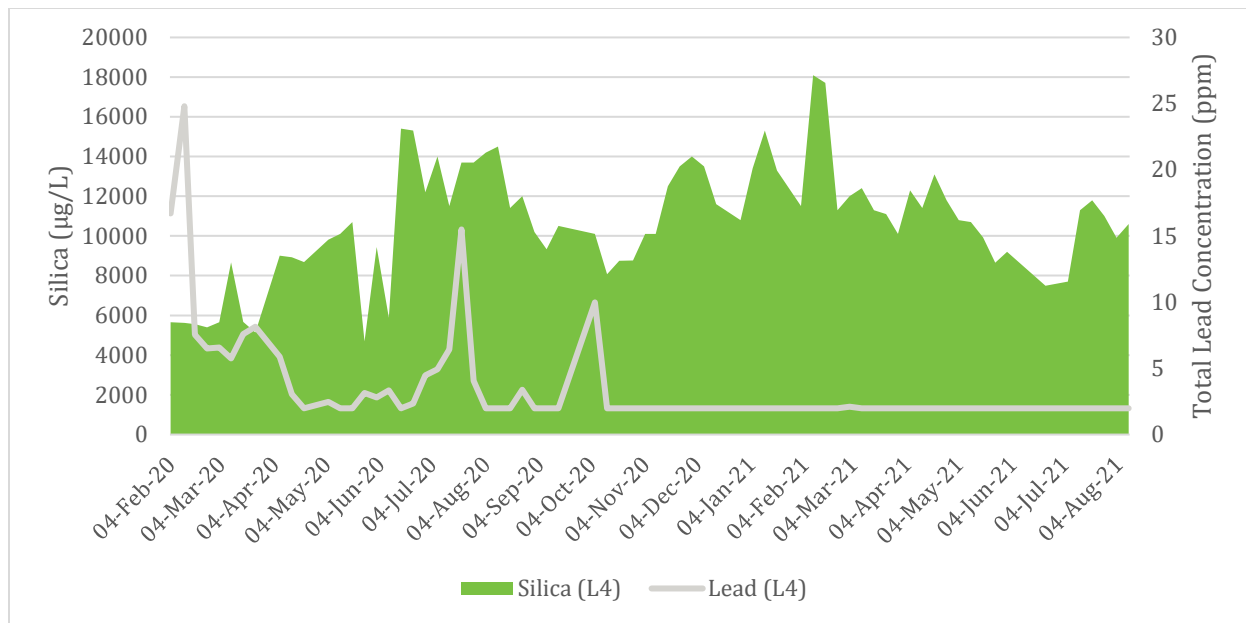


Figure 4 – Silica Residual and Lead Concentration for Loop 4 (Control Loop)

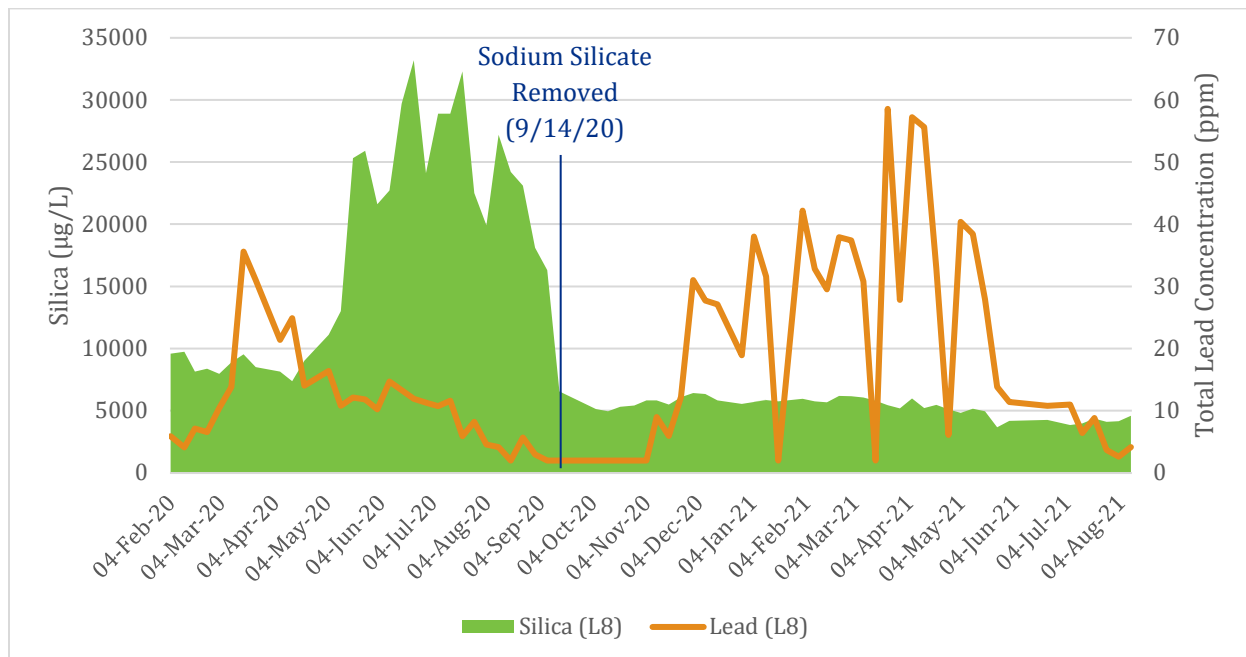


Figure 5 – Silica Residual and Lead Concentration for Loop 8

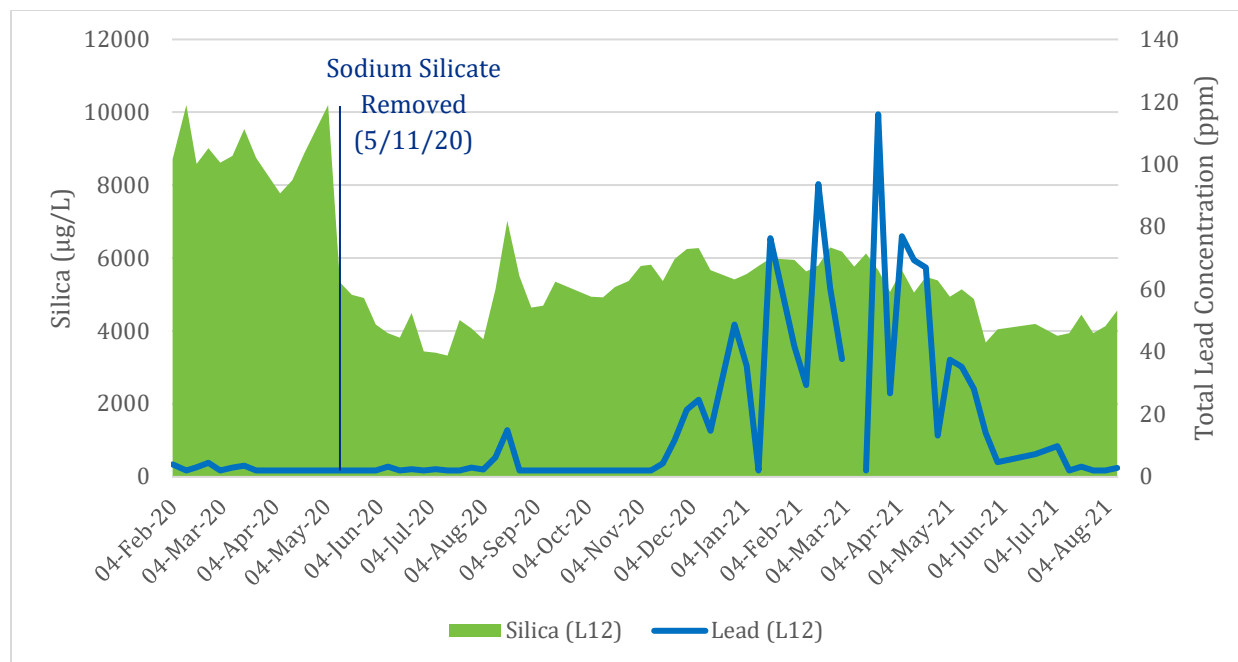


Figure 6 – Silica Residual and Lead Concentration for Loop 12

As shown in the figures, there is no consistent correlation between the silica residual concentrations and the stagnated lead concentrations. If only data from Loop 8 were available, one may be inclined to link the reduction in silica residual to the increase in lead concentrations that occur 2 months after sodium silicate dosing ceases in September 2020. However, the data for Loop 12 shows a similar spike in lead concentrations also starting in November 2020 and the sodium silicate dosing was ceased in May 2020, 6 months earlier, for Rack 3. With the sodium silicate addition being removed at separate points in the study timeline but the lead spike occurring at the same time, it is concluded the sodium silicate was not contributing to the low lead levels in the copper pipes with lead solder and did not cause the spike in lead levels starting in November 2020.

Conclusion and Recommendations

Section 3.4 in the CCT Effectiveness Report demonstrates that the current CCT with the addition of zinc orthophosphate is effective for Newark's Pequannock Gradient. With the samples collected for compliance and customer requested samples being first liter samples, the water tested is in contact with copper with lead solder and fixtures, rather than the lead pipe. Orthophosphate effectiveness against galvanic corrosion is clearly seen in the reduction in lead levels presented in the CCT Effectiveness Report. In addition, this supplemental memorandum confirms that the maintenance of a consistent orthophosphate residual is an effective mechanism for corrosion control against galvanic corrosion.

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an effective corrosion control mechanism against galvanic corrosion as shown in the distribution system and in the pipe loop study since June 1, 2021.

As discussed above, there has been no change to CSMR in the pipe loop study. Therefore, CSMR is not considered a reason for the increased lead concentrations.

The previous section described how sodium silicate was removed from the pilot study without a corresponding increase in lead levels. Therefore, it is recommended that Newark commence with reducing the sodium silicate dose and increase the lime dose. Although the sodium silicate was instantaneously stopped in the pilot, it is recommended that Newark slowly reduce their sodium silicate dose to 75%, 50% and 25%, with at least 2 months between each reduction, before removing it completely. In addition to Newark's current WQP sampling, compliance lead samples will be monitored with each reduction in sodium silicate dose to confirm that there are no negative impacts on corrosion control in the Pequannock Gradient from removing sodium silicate and replacing with lime to maintain pH.

cc: D. Hirsch, Bureau Chief, North Bureau of Water Compliance and Enforcement
S. Rizvi, BWSE – Engineering
M. Peters, BWSE – Engineering
K. Tedesco, Bureau Chief, BWSE – Engineering
S. DiMeglio, BSDW – Compliance Assistance Section
M. Athar, Newark
J. George, Newark